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13. ABSTRACT (Maximum 200 words)

This workshop promoted the exchange of information among researchers currently studying unsteady aerodynamics at high angle-of-attack and provided a basis for identification of the major, unresolved issues in this area. Detailed technical presentations were given covering AFOSR's 6.1 Trial in Unsteady Aerodynamics, namely Quasi-Two-Dimensional Unsteady Flows, Three-Dimensional Unsteady Flows and the Control of Unsteady Flows.



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# WHITE PAPER
# ON THE
# AFOSR SUPERMANEUVERABILITY WORKSHOP
# AT LEHIGH UNIVERSITY
# APRIL 9 AND 10, 1992

The goal of this Workshop was to promote the exchange of information among researchers currently studying unsteady aerodynamics at high angle-of-attack and to provide a basis for identification of the major, unresolved issues in this area. The format of the Workshop is given in Attachment 1. Representatives from both DARPA and NASA-Langley provided practical perspectives on high alpha research. These presentations were followed by detailed technical sessions covering AFOSR's 6.1 Triad in Unsteady Aerodynamics, namely Quasi-Two-Dimensional Unsteady Flows, Three-Dimensional Unsteady Flows and Control of Unsteady Flows. Attachments 2 through 5 provide, in bullet form, summaries of the objectives and issues that evolved from the Workshop. (Note: Copies of viewgraphs presented at the Workshop can be obtained by calling JoAnn Casciano at 215-758-4107.)

The following summary provides a brief profile of the major issues and concerns for the Air Force and the direction of emphasis of basic research in the area of unsteady aerodynamics.

## 1. QUASI-TWO-DIMENSIONAL UNSTEADY FLOWS

(a) The major physical features of this category are centered on the process of quasi-two-dimensional unsteady separation and subsequent development of the vortical flow structure. Quasi-two-dimensional flows include those past two-dimensional airfoils and moderately-swept wings, which may exhibit weak three-dimensional effects along their span. Moreover, end effects in the form of tip vortices, etc. may be present.

(b) AFOSR will begin to de-emphasize this phase of research, allowing the Army Research Office (ARO) to take the lead in two-dimensional unsteady separation theory, experiment and computation. AFOSR will still participate in leveraging the theory and computations for very selective research in this area including, for example, methods for controlling these flows in a smart manner in the initial stages of separation. Moreover, the influence of effects such as compressibility on two-dimensional flows are also of interest to AFOSR. Concepts such as trapping the dynamic stall vortex may not necessarily provide a high pay-off and are currently of less interest.

(c) AFOSR, in conjunction with ARO, is in the preliminary stages of defining a model problem and bringing together a team to focus on and elucidate the underlying theoretical mechanisms and sequence of events (initiation and evolution processes) as related to two-dimensional unsteady separation. This team will also attempt to sort out Reynolds number and pitch rate effects. Among the issues to be addressed is the influence of Reynolds number on the leading-separation phenomenon and the role of the trailing-edge region in relation to pitch-rate and Reynolds number, taking into consideration the values of these parameters in realistic flight regimes.

## 2. THREE-DIMENSIONAL UNSTEADY FLOWS

(a) The major physical issues in this category are centered around the processes of three-dimensional unsteady separation and vortex development including vortex breakdown and vortex asymmetry arising from flow past forebodies and wings undergoing transient maneuvers.

(b) AFOSR would like to bring together researchers to address the theoretical, computational, and experimental aspects of these flows, with accent on the underlying flow physics. These approaches include, for example, interpreting the flow structure

with the aid of topological representations, formulating leaner Navier-Stokes models to represent the dominant flow physics of higher Reynolds number flows, incorporating more effective models for the effects of transition and turbulence, and addressing the influence of compressibility and shock effects on vortex development and breakdown. Finally, research in this category will also address the flow physics and fluid-structure interactions associated with the impingement of three-dimensional unsteady vortical flows upon wing and tail components.

(c) Another key goal is to find better ways to integrate the results of unsteady aerodynamics research with flight dynamics issues, such as improving nonlinear aerodynamic models to account for history effects, hysteresis and aerodynamic bifurcations in order to maintain sound flight characteristics well into the post-stall regime.

## 3. CONTROL OF UNSTEADY FLOWS

(a) The key issues in this category involve controlling vortex formation and breakdown over wings and strakes (for roll authority) and past forebodies (for yaw authority). In a general sense, it is desired to control these complex vortex flows, either by local or global means, in order to achieve effective maneuvering at high alpha in a complementary role to thrust vectoring.

(b) Key questions for closed-loop control include: the degree to which knowledge of the detailed fluid mechanics is necessary for an effective control system; the adequacy of low-dimensional models for controlling unsteady flows; and the degree to which emphasis should be placed on nonlinear control schemes.

(c) Research endeavors in this area should also account for the concerns of the designer of the control system, namely input/output models that represent the physical quantity(ies) being sensed or controlled. Moreover, there exists a definite need for a reliable and unique indicator of the flow away from the surface.

## 4. SUMMARY

(a) The major goal of the AFOSR program on unsteady separated flows is to understand and control the flow physics in the high alpha regime, in order to provide dramatic improvements in fighter aircraft capabilities and performance. To this end, AFOSR is focussing its basic research on selected aspects of the underlying flow physics of two- and three-dimensional flows over lifting surfaces and bodies undergoing unsteady, high angle-of-attack maneuvers, with the intent of providing a basis for control of the flow structure.

(b) The research activities addressing the fundamental flow physics should be closely coordinated with corresponding studies in the area of applied flight dynamics, including the efforts underway at Wright Lab, DARPA, NASA-Langley, and NASA-Ames (6.2 and 6.3 programs). This coordination will allow the basic research programs to be focussed on the highest pay-off areas while keeping in perspective the near- and long-term goals of AFOSR.

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# AFOSR WORKSHOP ON SUPERMANEUVERABILITY: PHYSICS OF UNSTEADY FLOWS PAST LIFTING SURFACES AT HIGH ANGLE OF ATTACK

## *OVERVIEW OF TOPICS*

The overall objective of this Workshop is to address the unsteady flow structure past lifting surfaces during maneuvers to high angles of attack. The intent is to identify the crucial, unresolved issues and explore possible paths for their resolution. The topical areas to be addressed are defined in the following.

## I. QUASI-TWO-DIMENSIONAL FLOW STRUCTURE GENERATED BY TWO-DIMENSIONAL LIFTING SURFACES UNDERGOING PRESCRIBED MOTION

*Fundamental Phenomena*

- Flow separation from leading- and trailing-edges in relation to prescribed motion of lifting surface.
- Leading-edge vortex development as a consequence of flow separation.
- Localized (light) and global (deep) stall phenomena and their evolution from vortex development.
- Origin and consequences of possible three-dimensionality in nominally two-dimensional separation, vortex development and stall phenomena.
- Interpretation of foregoing aspects of flow structure in terms of vorticity, including its concentration near the surface (solid wall), its departure from the surface, and its subsequent rollup.
- Identification of principal features of unsteady flow structure that dictate unsteady loading on lifting surface and associated phase shift and hysteresis; use of basic vorticity balance concept to relate flow structure to loading.

*Format of Discussion*

- *Experimental* observations, limitations, and potential for gaining new insight
- *Theoretical* and *numerical* predictions and simulations, current limitations, and possibilities for further advances

## II. THREE-DIMENSIONAL FLOW STRUCTURE GENERATED BY THREE-DIMENSIONAL LIFTING SURFACES UNDERGOING PRESCRIBED MOTION.

*Fundamental Phenomena*

- Flow separation, leading-edge vortex development, and vortex breakdown from swept leading-edges subjected to defined motion.
- Evolution from flow separation to fully-stalled flow on swept wings including interactions between opposite leading-edge vortices.

- **Interpretation of foregoing aspects in terms of vorticity and definition of generic phenomena of separation and vortex development in three dimensions.**

- **Identification of major elements of unsteady flow structure that determine unsteady loading on lifting surface and associated phase shift and dynamic hysteresis; use of vorticity balance concept to relate flow structure to loading.**

*Format of Discussion*

- *Experimental* observations, limitations, and potential for gaining new insight

- *Theoretical* and *numerical* prediction and simulations, current limitations, and possibilities for further advances

## III. CONCEPTS OF CONTROL OF FLOW STRUCTURE ON TWO- AND THREE-DIMENSIONAL BODIES AND LIFTING SURFACES

Basic concepts of control, with emphasis on detailed flow structure associated with manipulation of flow separation and subsequent vorticity field/vortex development. Relationship between control concepts and fundamental phenomena addressed in (I) and (II).

*Fundamental Flow Physics Generic to Control Concepts*

- Control of initial separation, vortex development after separation and vortex breakdown.

- Interpretation of control concepts in terms of modifications of surface vorticity flux and convection of vorticity.

- Principal differences between two- and three-dimensional flow control concepts.

*Format of Discussion*

- *Passive control* involving surface modifications and extensions such as slats, flaps, and vortex generators.

- *Passive control* due to impingement of various classes of vortical structures and turbulence upon leading-edges, such as that from fuselages and canards incident upon wing and tail components.

- *Active control* by fluid-induced perturbations in the form of steady and unsteady bleed from surfaces and by structural perturbations such as oscillating flaps at leading-edges.

# ISSUES IN QUASI-TWO-D UNSTEADY FLOW

## OBJECTIVES:

- Understand cause-effect relationships of unsteady separation for application to maneuvering aircraft
- Maintain attached flow
- Pre-separation vorticity dynamics

## ISSUES

- Radically adaptive mesh
- High-Reynolds number flows
- Compressibility effects
- Non-equilibrium turbulence models, role of coherent structures
- High resolution of leading edge flows in experimental and computational studies
- Combined theoretical/numerical/experimental study-selected model problem

Note: Questions worthwhile considering for the model problem include:

a. What general features should be looked at in a given experiment to confirm or deny theoretical concepts?

b. What should be looked at in a set of calculations to compare with either theory or experiments?

c. What are the cause-and-effect relationshps of this type of flow field?

# THEORETICAL/COMPUTATIONAL ISSUES IN 3-D UNSTEADY FLOW

## OBJECTIVE:

### UNDERSTAND AND CONTROL

- **Unsteady boundary-layer eruption**
- **Vortex Breakdown and Vortex Asymmetry**

## APPROACH

- **Further theoretical work on unsteady 3-D boundary layers, bifurcations, and chaotic solutions**
- **Accurate numerical simulation of 3-D unsteady viscous flow at higher Reynolds number, including compressibility and turbulence.**

## ISSUES:

- Interpretation of flow physics from observed topological features
- Mathematical modeling
  - ✓ NS,TLNS, RANS, RA-TLNS
  - ✓ Need <u>leaner</u> models to simulate higher Re with appropriate resolution
  - ✓ Pseudo-time dependent approaches
- Compressible-flow effects
- Turbulence effects: Reynolds stress models, LES, DNS
- Moving/flow-adaptive multi-block grid techniques
- Resolution of scales, computing resources
  - ✓ High-performance computing (interdisciplinary)
  - ✓ Post-processing resources: hardware and software
- Far-field B.C.'s: external and internal flow
- Interaction with other disciplines: structural dynamics, acoustics, controls, computer science
- Synergism between theory/experiment/computation

# EXPERIMENTAL ISSUES IN THREE-D UNSTEADY FLOW

## FLOW PHYSICS:

- **Vortex breakdown**
- **Three-D separation and vortex formation**
- **Asymmetry of vortices - origin and interaction**
- **Vortex-shock interactions**
- **Role of turbulence in three-D vortical flows**
- **Transition and Reynolds number effects**
- **Quantitative interpretation of flow physics - surface and flow topologies**

## BENCHMARK PROBLEMS/EXPERIMENTS:

- Surface versus flowfield quantities for defined cases:

  ✓ Steady motion of wing or body
  ✓ Self-excited motion of wing or body
  ✓ Forced excitation of wing or body
  ✓ Buffeting of wing or body

- Consistent definition of configurations and parameters

  ✓ Geometry
  ✓ K, $\dot{\alpha}C/2U$, Pitch Axis, $\overline{\alpha}$, $\alpha_i$, $\alpha_f$
  ✓ Mode coupling
  ✓ Reynolds number

## EXPERIMENTAL CONCERNS:

- Blockage corrections
- Support interference
- Inflow/outflow conditions
- Reliable and unique surface indicator of flow conditions away from surface
- Instantaneous versus time-/phase-averaged approaches

# CONTROL ISSUES IN TWO-D AND THREE-D UNSTEADY FLOW

## OBJECTIVE:

- Change from an *initial state* to a *final state* through a desired *path* over desired *time*

## APPROACH:

- Control of *vorticity*, *production* and the management of *dynamics* (separation, diffusion, distribution) of *vorticity and vortices* through:

  ✓ Influence on basic flow
  ✓ Influence on instabilities

## NEED TO DEFINE:

- Control objectives
- Performance measures

## ISSUES:

- Understanding of flow physics including two-D and complex three-D flows
- Effective implementation of actuators and sensors

  ✓ Smart materials
  ✓ Micromachines

- Control techniques including integration with flight dynamics concepts